Long-Term Average Spectra of Adult Iranian Speakers' Voice

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Summary: Introduction. Long-term average spectrum (LTAS) allows quantifying the voice quality and provides an overview of the mean spectral characteristics of a voice. The aims of this study were to survey normal spectral characteristics of Persian and investigate sex-related changes in the source characteristics of dynamic speech using LTAS.

Method. Speech samples obtained from 30 male and 30 female Persian-speaking participants reading a text in habitual pitch and loudness level. At the LTAS window and using *Praat* software, the amplitude values were obtained at equal intervals of 160 Hz, ranging from 0 to 8 kHz.

Results. The main features of the average spectrum were as follows: peak in the region of 480 Hz with a reduction at higher frequencies, a 20 dB decline from 480 to 960 Hz, a flat region from 960 to 1920 Hz, a further decline from 1920 to 3040 Hz, and a further flat region from 3040 to 8000 Hz. In comparison to men, women revealed significant lower levels of amplitude at frequencies of 160 and 320 Hz and higher levels of amplitude at frequencies of 960, 3360, 3520, 3680, 3840, and 5920 Hz.

Conclusion. The overall shape and gender-related energy distribution pattern of the LTAS of Persian were more similar to those of English than to those of Korean. The more phonetic differences between Persian and Korean compared with Persian and English might contribute to different spectral characteristics. The present study tried to clarify the spectral characteristics of Iranian male and female voices and focused on more breathy voice quality for women than men.

Key Words: Spectral characteristics–Voice quality–Breathiness–Persian.

INTRODUCTION

Spectral measurements provide information about laryngeal functions and articulatory movements. Visual examination of spectrograms, a sort of spectral measurements, provides valuable information about voice source and vocal tract filter characteristics of the sound. Often, however, greater objectivity is needed in characterizing certain features of the spectrograms. A more objective measure can be offered by long-term average spectrum (LTAS), which provides information on spectral energy distribution of speech signal during a relatively long speech sample. Including only voiced sounds in the analysis of LTAS would contribute to the avoidance of the confounding influence on the averaged spectrum of phonemes. These phonemes have a source other than the vocal folds (such as voiceless consonants). Some applications for clinical and research purposes have been documented for LTAS including: assessing overall perceived voice quality,[1–4] evaluating overall intelligibility of speech and speech clarity,[5] providing a normal database for spectral measurements,[6,7] making differentiated sex and age groups from each other,[8–10] studying voice therapeutic process and comparing the effectiveness of different treatment approaches,[11–13] developing a formula for fitting more suitable hearing aids for native speakers of each language,[14,15] and studying emotional states and effects.[2,16]

Most reports of the LTAS conducted in the literature have been published in English (American,[17–19] British,[20] or Australian[21]), although there are some studies in other languages such as Swedish,[22] Finnish,[4] Dutch,[23] Spanish,[9] Portuguese,[24] Korean,[5] and so forth. Byrne et al[25] mentioned that the LTAS is similar across 12 studied languages (English [several dialects], Swedish, Danish, German, French [Canadian], Japanese, Cantonese, Mandarin, Russian, Welsh, Singhalese, and Vietnamese), although many statistically significant differences have been found among them. They finally suggested a "universal" *long-term average spectrum of speech (LTASS)* across languages for many clinical and research objectives such as prescription and evaluation of hearing aid fitting and the Articulation Index used in fitting procedures of hearing aid.[25] The languages they studied demonstrated many statistically significant differences, differing up to 3 dB from the mean values. They suggested that the differences in the distribution of phonemes among the different languages might contribute to variations in LTASS.[25] Kent and Read[26] cited Byrne et al[25] in their textbook and suggested that "It appears that the LTAS is similar across languages."

Some studies have surveyed the LTAS in different languages and interestingly, they have found some differences. In a later study, Noh and Lee[10] tried to identify the differences of LTAS between Korean and English speakers in passage reading. A Korean and an English passage were selected to be read and each participant read the passage of her own language. Results demonstrated that for male participants, the LTASS of Korean

Accepted for publication September 4, 2013.
This work has been funded by Tehran university of medical sciences.

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Journal of Voice, Vol. 28, No. 3, pp. 305-310
0892-1997/$36.00

http://dx.doi.org/10.1016/j.jvoice.2013.09.002

speakers was significantly lower than that of English speakers in frequencies above 1.6 kHz except at 4 kHz and its difference was more than 5 dB, especially at higher frequencies. For women, the LTASS of Korean speakers showed significantly lower levels at 0.2, 0.5, 1, 1.25, 2, 2.5, 6.3, 8, and 10 kHz, but the differences were less than 5 dB. Compared with English speakers, the LTASS of Korean speakers showed significantly lower levels in frequencies above 2 kHz except at 4 kHz. The difference was less than 5 dB between 2 and 5 kHz but more than 5 dB above 6 kHz. They concluded that the LTAS is not the same for Korean and English; therefore, it should be considered in clinical and research purposes and they also concluded that "universal LTAS" cannot be appropriate for all languages, especially for Korean.

Boullosa and Pérez Ruíz[7] studied the LTAS in Spanish speakers and reported differences between Spanish and English spectra in the region of 1 kHz and from 3 kHz upward. Some interlanguage spectrum differences—either significant or insignificant—were reported for Polish and English,[27] French and Nimboran,[28] Hungarian, Swedish, and German.[29] Pavlovic et al[6] reported some insignificant spectral differences among Danish, German, Italian, English, and French. However, they focused on the provision of normative values of LTAS in each language and proposed that normative values of LTAS can be specified across the studied languages. They also reported significant sex differences and norms for each sex.[6]

White[8] asked listeners to judge the perceived sex of Swedish children's voices and reported that children whom the listeners correctly judged to be boys had a peak at 5 kHz in the LTAS, whereas those accurately perceived to be girls did not have. Sergeant and Welch[20] studied gender differences of English children's voice using LTAS and found that there are no differences between LTAS curves of boys and girls, whereas White[8] demonstrated sexual differences in Swedish children. Comparing what White[8] reported about Swedish children and what Sergeant and Welch[20] reported about English Children, some interlanguage differences can be predicted between Swedish and English.

It seems that small interlanguage differences can be expected. More research in different languages needs to be conducted and the normative values of LTAS in each language could be helpful to have a more accurate function in research and clinical practice. Byrne et al[25] did not include Persian in their research. The number of vowels and voiced consonants in English is more than that of Persian.[30,31] Persian is an Iranian language belonging to the Indio-European language family. Persian is classified as a subject-object-verb language and it is not a tone language. The sound system of Persian consists of eight stops, eight fricatives, two affricatives, two nasals and two liquids, a glide, and six vowels.[32] There is no information about the spectral characteristics of Persian speaker's voice in the literature. Therefore, the first aim of this study was the provision of normative LTAS data in Persian speakers of Iran.

Mendoza et al[9] found differences in male and female voice quality of Spanish speakers using LTAS. They reported that the female voice exhibited greater levels of energy in the spectral regions related to the third formant, which causes women's voice to have a more "breathy" quality than men's. The lower spectral tilt in the female voice is another finding of their research.[9] According to their study, although both American and Spanish women's voices were perceived more breathier than men's, the breathiness quality of American female voice is less than that of Spanish female voice. The authors mentioned that this kind of voice quality may be the result of a sociocultural behavior, at least among Spanish and American women community. They suggested that it would be necessary to survey gender differences of voice quality in other nationalities.[9] Noh and Lee[5] demonstrated that the LTAS of Korean women was lower at low frequencies, but higher at 630, 800, 1600, 5000, and 10 000 Hz than the LTAS of Korean men. Based on what reported by Noh and Lee,[5] the sexual differences reported for Korean were different from American and Spanish. Therefore, the second aim of the present study was to compare sexual differences among Persian speakers.

METHOD

Thirty male and 30 female Persian speakers participated in this cross-sectional study. The male participants ranged in age from 22 to 26 years (mean = 23.8 years) and the female participants ranged from 19 to 25 years (mean = 22.5 years). None reported a history of speech or auditory problem or symptoms of cold or acute respiratory infection during the length of their involvement in the study. Also, the participants did not have upper respiratory tract infection during the 3 weeks before the test day. All the participants were requested to fill in the Persian version of voice handicap index (P-VHI) questionnaire. Based on Moradi et al (2013), the cutoff point at the P-VHI is equal to 14.5 to distinguish individuals with and without voice disorders. Therefore, the total P-VHI of the people who participated in this study was lower than 14.5.

An otorhinolaryngologist and a speech and language pathologist were asked to evaluate subjects' voices using a comprehensive voice assessment form. This form comprised the components of a medical history, an oral examination, and the perceptual, acoustic, and respiratory assessments. They also performed videostroboscopy. According to the reports by otorhinolaryngologist and speech and language pathologist, the participants who were included did not have voice disorders, and based on the videostroboscopic findings, no problems were observed in their laryngeal structure and function. The participants' voices were also perceptually assessed with the GRBAS (grade, roughness, breathiness, asthenicity, and strain) scale[33] by three more speech and language pathologists who were expert in the voice field. The participants who had scored higher than 0, even if it was on one measure and by one speech and language pathologist, were excluded from the experiment. None of the women participating in the study were in the menstrual cycle during the test time. All participants had the criteria of being nonsmokers and signed the written informed consent form to participate in the study.

All participants' voices were recorded during a read-aloud task of a 240 word standard text with phonemic balance[34] in their natural voice and at a normal reading speed. Before recording, all participants were asked to practice the reading text to be fluent and familiar with the task. The duration of each recording was about 180 seconds. The recordings were perceptually monitored by the first author, and the participants were asked to read again if they had not read in their natural voice and at a normal reading speed. Due to the effect of intensity on LTAS, the participants are instructed to read in their habitual loudness. Based on the results of Nordenberg and Sundberg,[35] Master et al[36] concluded that researchers who aim to involve sound pressure level measurements and the participant's voice recording in their investigations must carefully control for data collection procedures. However, in the present study, like some previous researches,[4,19,37] only reading at the habitual loudness level was monitored. The involvement of sound pressure level measurements was not aimed at in this study. Furthermore, no differences were reported between Persian male and female speakers' habitual intensity in reading tasks.[38]

Acoustic data were gathered using a unidirectional dynamic cardioid microphone (model C410; AKG Acoustics, Vienna, Austria) positioned at a distance of 6 cm from the speaker's lips and recorded using an external audio interface (US-122mkII; TASCAM, China) at a sampling rate of 44.1 kHz. All recording samples took place in a soundproof booth.

To facilitate comparisons between studies, the procedure outlined by other authors was followed in this study.[8,9,17,18,24] Therefore, using Hanning window, the amplitude values were also measured at intervals of 160 Hz throughout the frequency range of 0–8 kHz (160, 320, 480, 640, …, 8000), with a time resolution of 40 milliseconds. For each speaker, a total of 50 amplitude measurements were obtained.

The acoustic measurements were all obtained automatically by the *Praat* software (Version 5.1.17).[39] Similar to the previous studies,[8,17,24] 40 seconds of the center of each sample was analyzed, which is regarded as sufficient to get the LTAS independent of the speech material.[40,41] Based on Kitzing[41] and Löfqvist,[40] if the speech signal to be analyzed lasts long enough, from 20 to 40 seconds, the resulting mean spectrum will not be strongly affected by differences in the speech material.[36,40,41]

According to Lofqvist and Mandersson,[42] unvoiced elements in the LTAS analysis would corrupt data. Therefore, to perform the LTAS, all devoiced sounds, pauses, and silences were automatically excluded from the analysis by the script used by da Silva et al[24] with the permission of the authors.

The spectra were normalized to facilitate the measurements and comparison between spectra based on what had been suggested by Master et al[36]: "normalization means placing the strongest component of the spectrum in 0 dB and the other components in negative values in dB."

To evaluate the differences in the energy distribution of different frequency levels between male and female spectra, a repeated measures analysis of variance (rANOVA) was performed. The significance level of the derived data was considered as less than 0.05.

To specify the frequency levels at which there could be differences between male and female spectra, the multiple independent *t* tests were used with the purpose of comparing amplitudes at each of the 50 frequency levels in both gender groups. To control the increased risks of type 1 errors, Bonferroni corrections were performed and a more stringent alpha level for each comparison was set ($P < 0.001$).

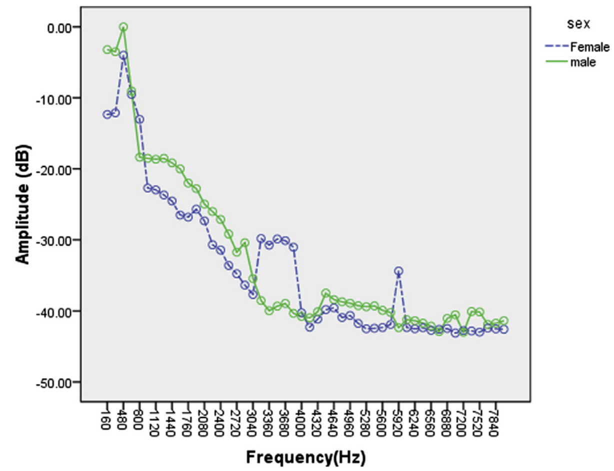

FIGURE 1. Mean spectral energy values for women and men at each of the 50 frequency levels.

The *Statistical Package for the Social Sciences*, Version 16.0 (SPSS Inc, Chicago, IL) was used to perform all statistical analyses.

RESULTS

Mean spectral energy values for women and men at each of the 50 frequency levels are shown in Figure 1. The highest amplitude in the female voice occurred in the region of 320 Hz, whereas it was observed in the region of 160 Hz for men.

The average spectrum for all participants demonstrated that there is a peak in the region of 480 Hz with a reduction at higher frequencies. A 20 dB decrease was found from the frequency of 480–960 Hz. The difference was less than 4 dB between 960 and 1920 Hz, so there was a flat region between 960 and 1920 Hz. A 12-dB intensity difference was observed between 1920 and 3040 Hz. The difference was less than 6 dB from 3040 to 8000 Hz (Figure 2).

The results of rANOVA revealed that there was a significant between-subject effect for the sex factor $F(1,30) = 3.095$, $P = 0.001$.

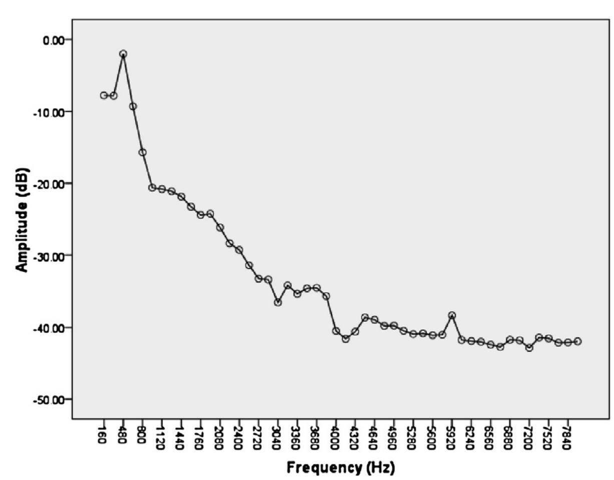

FIGURE 2. The average spectrum for all participants.

The results of the multiple independent *t* tests showed that the LTAS of women was lower than that of men at lower frequencies, and the difference was statistically significant at 160 and 320 Hz ($P < 0.001$), but the LTAS of men was significantly lower than that of women at 960, 3360, 3520, 3680, 3840, and 5920 Hz ($P < 0.001$).

DISCUSSION

Two aims followed in the present study were the provision of normative LTAS data in Persian speakers of Iran and comparison of sexual differences among Persian speakers. To achieve these purposes, LTAS of Persian was explored for 30 male and 30 female Persian-speaking participants reading a text in habitual pitch and loudness level.

Based on the results of normative LTAS data obtained from Persian speakers of Iran, the average spectrum for all participants was achieved so that there is a peak in the region of 480 Hz with a reduction at higher frequencies. A 20 dB decrease was found from the frequency of 480–960 Hz. The difference was less than 4 dB between 960 and 1920 Hz, so there was a flat region between 960 and 1920 Hz. A 12-dB intensity difference was observed between 1920 and 3040 Hz. The difference was less than 6 dB from 3040 to 8000 Hz (Figure 2).

Considering the average spectrum for all participants, we cannot compare the results of the present study regarding the overall level and shape of the speech spectrum directly with that of other studies[7,10,15,25] because they can be affected by study design, equipments, and acoustic analysis methods applied in different studies.[10] However, using indirect comparison, it can be found that the overall shape of the LTAS of Persian speakers was almost similar to those of English speakers reported by Noh and Lee,[10] Byrne et al,[25] and Cox and Moore[15] and Spanish speakers reported by Boullosa and Pérez Ruíz.[7] The difference observed between Persian and Korean speakers[10] was due to the fact that the Persian spectrum had a large flat region from 3000 to 8000 Hz, whereas the Korean spectrum showed an incline through this frequency level.

It seems that the differences in the distribution of phonemes among different languages might also contribute to variations in LTAS. Noh and Lee[10] suggested that some differences found in the LTAS of English and Korean were expected to be the result of differences between English phonemes and Korean phonemes. There are some differences between English and Persian regarding the distribution of phonemes. Persian has six vowels and 23 consonants. Although most phonemes are similar between English and Persian, /ɣ/ and /ʕ/ are two voiced consonants in Persian which are different from English and there are /θ/, /ð/, and /w/ in English which are not in Persian.[32] However, this can be explained by the fact that there is more similarity of distribution of high-frequency phonemes between English[30] and Persian[31] as compared with the similarity in this regard between Persian and Korean.[43] It seems that the distribution of high-frequency phonemes in Korean is less than Persian. The lower distribution of high-frequency phonemes can lead to lower energy levels in the high-frequency regions. For example, fricative consonants are high-frequency phonemes. Korean has three fricatives, namely /s/, /s*/, and /h/.[44,45] However, Persian has eight fricative consonants, namely /f/, /v/, /s/, /z/, /ʃ/, /ʒ/, /x/, and /h/.[32]

The results about the second purpose revealed that the distribution of energy was significantly different between female and male spectra ($P = 0.001$). The highest amplitude is not the same for female and male voices, it occurred in the regions of 320 and 160 Hz for female and male voices, respectively. This spectral difference between two sex groups agrees with the previous studies and can be related to sex-related differences regarding fundamental frequency in Persian which are similar to other languages.[25]

Compared with the LTAS of men, women's LTAS was significantly lower at low frequencies (160 and 320 Hz). This finding agrees with what has been reported by Byrne et al[25] for other languages. Based on the results of their study, the LTAS of female spectra was significantly lower than that of male spectra at low frequencies ranging from 63 to 250 Hz. This finding is also consistent with that of Noh and Lee.[10] They demonstrated that the LTAS of women was significantly lower than that of men at low frequencies (100, 125, 250, and 315 Hz).

The reduction of low-frequency gain may result in more clear and intelligible speech of women in comparison with men. It has been found that a decrease in low-frequency energy can increase the speech recognition in background noise.[46] It can be assumed that decrease in low-frequency energy can result in improvement of the signal-to-noise ratio due to the fact that the background noise contains the energy in the low-frequency region.[5,46]

The LTAS of men was significantly lower than that of women at frequency points of 960, 3360, 3520, 3680, 3840, and 5920 Hz. This agrees with Klatt and Klatt[47] and Mendoza et al.[9] Among the mentioned frequencies, the frequency points of 3360, 3520, 3680, 3840 Hz are located near the third formant, and the results demonstrated that the gain of these frequencies are higher for women than men. Klatt and Klatt[47] proposed that the acoustic characteristics of women's voice may result in perception of breathier voice quality than men's. Closure glottal pattern and its effects on acoustic characteristics may play a prominent role in the perception of gender from speech.[48]

Stroboscopic findings show that Posterior glottal gap is a common glottal closure in women[49] and incomplete glottal closure occurs significantly more for women than men.[50] Posterior glottal gap also occurs for Persian-speaking women more than men.[51] This closure glottal pattern during phonation can cause aspirated noise which can be related to perceptually breathy voice.[47] Klatt and Klatt[47] assumed that the existence of a posterior glottal gap during female speech can produce aspirated noise in the region of third formant, thus higher gain near third formant can be expected in female voice.[52]

This finding is not identical to that of Byrne et al[25] who reported that male and female spectra are almost similar over the frequency range from 250 to 5000 Hz. Moreover, this result does not agree with what has been mentioned about Korean female and male speech. It has been considered that more open glottal configuration results in a greater aspirated noise[53] and that there is a positive correlation between the size of glottal gap and the amplitude of third formant.[48] Thus, the disagreement between the result of the present study and the two above-mentioned studies can be explained by the significant effect of glottal configuration on the amplitude of third formant. The glottal closure pattern and the prominent pattern for men and women may be different among different languages and the participants of the various studies. Certainly, more research is needed regarding gender-related differences of glottal closure patterns.

In comparison with women, men demonstrated higher spectral amplitude levels in the frequency region of 5 kHz. For Persian speakers, the amplitude mean showed a peak at 5 kHz for men, whereas a flat spectrum was found for women. An observable and prominent difference (±7 dB) in the curve of men and women can be seen at 5 kHz in Figure 1. This result is coordinated with the findings of White[8] who reported that children whom the listeners correctly judged to be boys had a peak at 5 kHz in the LTAS. This finding does not agree with what h,as been mentioned in American English and Spanish.[7,9] According to Byrne et al,[25] there are significant sex-related differences in the frequency range more than 5000 Hz and there are much differences among studied languages. Byrne et al[25] mentioned that these sex-related differences among different languages may be due to the effect of sociocultural differences on voice quality.

CONCLUSION

In this study, we aimed to survey normal spectral characteristics of Persian and investigate the sex-related changes in the source characteristics of dynamic speech using LTAS. The findings demonstrated that the overall shape of the LTAS of Persian is almost similar to that of English and different from that of Korean. Different energy distribution patterns were found for Persian-speaking men and women's voices which are a little different from American English and Spanish and somehow from Korean. The more phonetic differences between Persian and Korean compared with Persian and English might contribute to different spectral characteristics. Thus, it seems that further investigation is needed to obtain the normal spectral characteristics of LTAS and gender-related differences related to LTAS for each language. The present study tried to clarify the spectral characteristics of Iranian male and female voices. The higher amplitude levels located in spectral regions related to the third formant demonstrate that the voice quality of Iranian women is breathier than the voice quality of Iranian men.

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